Development of a Polarimeter for Astrophysical Applications in the Midinfrared

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Introduction

The polarization of light from astrophysical sources is an important indicator of the environment and physical processes at work in the emission region, as well as in the intervening medium. Understanding processes such as the life cycle of stars and the synthesis of interstellar material increases our knowledge of how the material that is the basis of everything around us arrived at the proper point and at the proper time to create the observed universe. Our approach is to combine the imaging capabilities of a midinfrared array camera with an externally mounted polarimeter to obtain geometrical information about astrophysical environments otherwise obscured from view.

Statement of problem

Dust grains associated with a variety of astrophysical settings absorb and reradiate energy at infrared wavelengths. Comparisons of midinfrared (10 μm) and near-infrared (2.2 μm) polarization maps show that observations at these wavelengths probe different regimes and that the polarization produced at these wavelengths arises from very different mechanisms. At 2.2 μm, the high degree of polarization measured is produced by scattered light. At 10 μm, grains cannot scatter efficiently (due to the size of the grain compared to the wavelength of the light) and therefore the polarization is dominated by dichroic absorption due to aligned grains. The mechanism at 2.2 μm reveals information about the illuminating sources because the orientation of the maximum electric vector remains orthogonal to the direction of illumination. The mechanism at 10 μm produces polarization by preferentially absorbing one component of the electric vector over the other. This can only happen if the grains are highly aligned and elongated, so maps of 10 μm polarization provide information about the dust grains and their orientation. The comparison of the polarization maps at those two wavelengths will reveal new information about the geometry and composition of the gas, dust, and stars.

To illustrate the usefulness of this technique, consider the center of our galaxy, which remains hidden from view at optical wavelengths. Infrared studies have provided much of the current information about the galactic center. Polarimetric studies at 2.2 μm have revealed the distribution of dust and some of the illuminating sources. Midinfrared polarimetric studies have revealed information concerning grain alignment and the effect of magnetic fields. Until now, polarization studies in the midinfrared could be done only by using single detector technology. Figure 1 represents the best midinfrared polarization map of the galactic center that exists today. The polarization measurements for that map were painstakingly made one at a time in a separate experiment from the one that provided the underlying photometric map. The infrared sources labeled IRS1, 10, 5, and 8 all have strong intrinsic polarization, which is thought to be due to the alignment of grains surrounding the sources. The position angle of the maximum electric vector and the magnitude of the polarization are consistent with that which would be produced by a strong magnetic field (>10μG) (Aitken, et al., 1986). Such a strong field would have significant impact on the structure and evolution of the galactic center. The change in position angle and the smaller polarization seen in the other sources in figure 1 is attributed to differences in grain composition and alignment in the southern portion of the map. The Ames 10-μm polarimetric imager can simultaneously provide photometric and polarimetric images of a 14- by 14-in. area of the sky and increase the resolution of the map shown in figure 1 to a resolution of 1 in. per pixel (as shown by the box in the upper right hand portion of the figure).

Instrumentation and methods

NASA-ARC 10/20 μm camera: A new infrared camera (AIR Camera) has been developed at NASA Ames Research Center for observations from ground-based telescopes. The heart of the camera is a Hughes 58 × 62 pixel arsenic-doped silicon detector array that has the spectral sensitivity range to allow observations in both the 10- and 20-micron atmospheric windows. Three discrete 8% filters at 18, 20, and 22 microns, a 3% circular variable filter covering the 7.5- to 14-micron atmospheric window, and discrete 10% filters centered at 9.8 and 10.3 microns can be selected to define the spectral resolution. A very flexible optical design and a dedicated guider/mounting box allow camera operation at any major telescope that has a focal ratio of 17 to 45. The camera has been used for observing runs

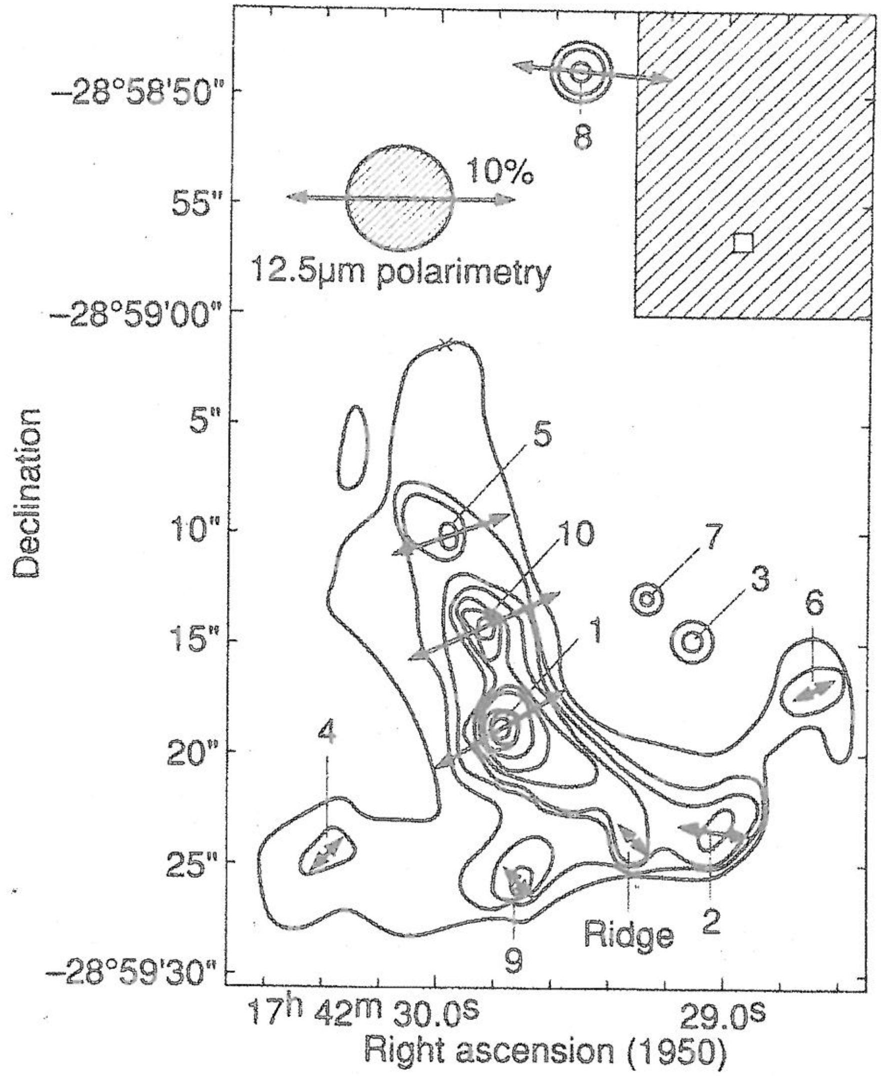

Figure 1. Intrinsic 12.5 μm polarization measurements of the galactic center (Aitken et al., 1986) superposed on the 12.5 μm flux contour map (Becklin et al., 1978). The length of the dark lines indicates the percentage polarization while the orientation of the line shows the position angle. The array size of the 10 μm camera is shown by the cross-hatched box in the upper right corner and the pixel size is drawn in as a 1-inch square.

at the Mt. Lemmon 1.5-m NASA/UA telescope. When using this telescope, each camera pixel corresponded to a square 0.73 arc-seconds wide on the sky, which gave a total camera field-of-view of 42 × 45 arc-seconds. At the NASA Infrared Telescope Facility in Hawaii a smaller pixel scale gives a 14-in. field-of-view.

The optics of the AIR Camera are very simple, consisting of a single lens that simultaneously reimages the sky image formed by the telescope onto the detector array as it images the telescope secondary mirror onto a cold stop at the entrance to the array enclosure. Two filter wheels select from among the available filters, rotating them into positions just in front of the cold stop. The optical design (fig. 2) allows changing between telescopes of different focal ratios by changing the reimaging lens while keeping the filter wheels, cold stop, and array undisturbed.

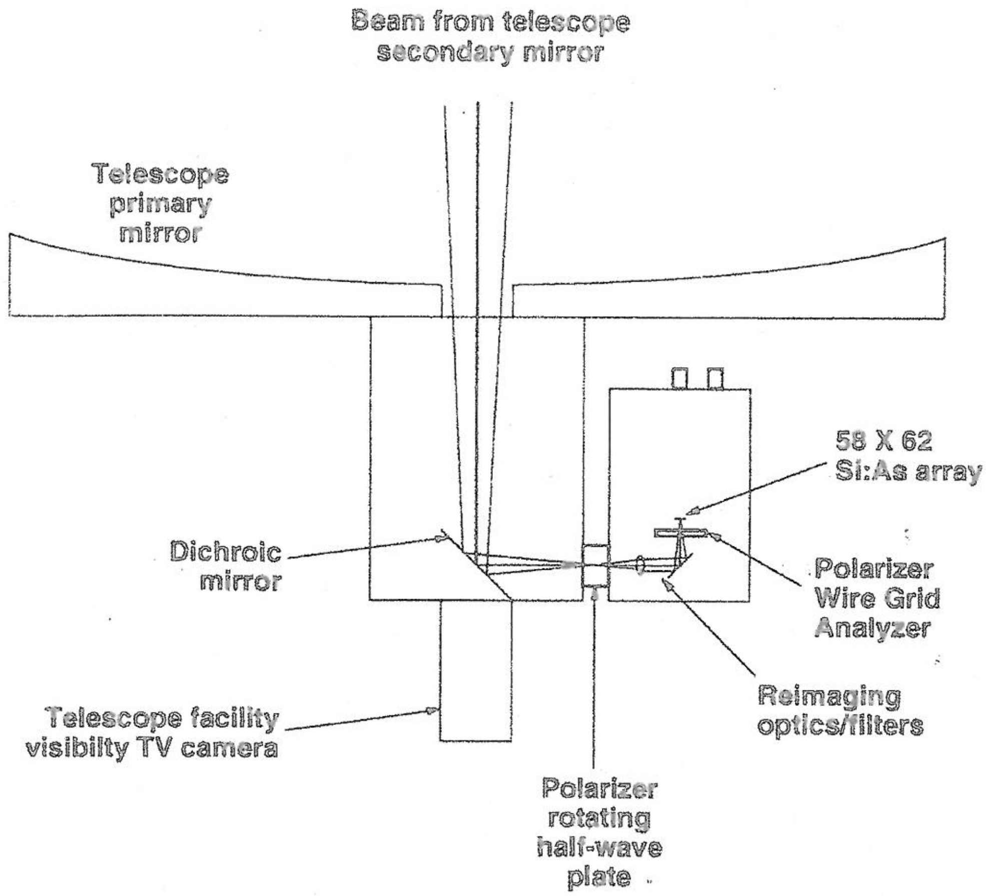

Figure 2. Schematic representation of the polarimeter and midinfrared camera assembly.

Ames midinfrared polarimeter

The design of the near-infrared polarimeter consists of a fixed wiregrid analyzer (which is cryogenically cooled) and a rotating half wave plate. The materials used for the optical components are an Ar coated germanium wiregrid and a cadmium sulfide half waveplate. These materials were chosen because they provide optimum characteristics for midinfrared polarimetry. The wiregrid analyzer resides in a filter wheel position inside the cryogenically cooled camera. The rotating half wave plate is housed inside a cylindrical mount that is motor driven.

Astronomical results

In figure 3(a–b) we present new astronomical images obtained with the AIR Camera at NASA's Mt. Lemmon telescope. These images show emissions from the young planetary nebula NGC 7027 at two midinfrared wavelengths. Planetary nebulae are the ejected envelopes of evolved stars. The central star of NGC 7027 is totally obscured by dust in the optical, has a temperature of 180,000 to 234,000 K, and is located approximately 1 kpc from our Sun. The midinfrared images reveal a double lobed structure and a central minimum, which represent a cross-section of a tipped toroid of gas and dust. The dust ejected by planetary nebulae has been enriched with heavy elements created through the star's nucleosynthesis. The nebula also contains large carbon molecules, which may be the building blocks of prebiotic material. This material is ultimately reincorporated into the interstellar medium from which new stars will be formed.

Ongoing research efforts

Now that the AIR Camera has been tested at the telescope, the polarimeter can be used in conjunction with the camera. The next step in this project includes taking the camera/polarimeter to various telescopes to observe objects such as NGC 7027 and the galactic center to further study a variety of astrophysical environments.

References

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Key words

Midinfrared polarimetry, Two-dimensional array camera